

ON IMPROVEMENTS OF AND SUGGESTIONS ABOUT GPS “COMMON VIEW” WITH MULTICHANNEL TIME RECEIVERS - FIRST RESULTS

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Abstract

At present time the international timing community has access to multichannel GPS and GLONASS time receivers. This new generation of time receivers offers a great potential to time users and timing labs can benefit from. One advantage is the continuous monitoring of the satellite clocks with the possibility for easy implementation of an international tracking schedule which need not be updated. Otherwise the user can perform study work in changing various processing parameters. If one uses high rate data (i.e. at one-second sample rate), investigations can be done in much more detail. This also leads into application of carrier phase observable if the receiver is capable of such measurements.

In this paper we give first results of "Common View" clock synchronization between DLR and BIPM using AOA TTR-4P GPS time receivers with GGTTs data format version 1 output. Due to repeated problems with the BIPM receiver, NPL supported us with corresponding data files. C/A-code measurements have been analyzed and compared to data with usual one-channel receivers. Both results have been analyzed in view of precision and availability of synchronization data. Recommendations will be given for application of multichannel receivers for clock synchronization. It will be concluded that such receivers will certainly have a large impact for future clock synchronization, and far more investigation work is still required.

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INTRODUCTION

The GPS "Common-View" method is the routine operation to make worldwide accurate clock synchronization successful. Also GLONASS offers such possibilities, and some labs are investigating this method to be established as a tool for the timing community [1].

The "Common View" method as implemented with conventional one-channel C/A time receivers, has some drawbacks which could be summarized here:

- A dedicated tracking schedule has to be implemented for each Earth's region;
- The need to update the tracking schedule twice per year (due to orbit satellite orbit changes /drifts);
- Only pseudo-range data are available (no carrier phase measurement);
- Ionospheric delay measurements are usually unavailable;
- Most of present receivers have a very limited memory (no real-time offload to a PC etc.) resulting in user made restrictions.

Now, new multichannel GPS time receivers and geodetic multichannel GPS receivers modified for time applications are available. The Allen Osborne Associates (AOA) TTR-4P GPS time receiver is one of them and will be studied in this work. This paper we will mainly refer to "Common View" and "stand-alone operation" application.

The TTR-4P is an enhancement of the Turbo Rogue GPS receiver architecture that was developed at the Jet Propulsion Laboratories (JPL) under the NASA Geodynamics Program [2]. The goal was to provide a field-worthy geodetic receiver with accuracy to suit the most demanding applications. The TTR-4P was jointly developed by AOA and JPL for missions requiring GPS data of very high precision and accuracy. Prospective applications included: geodesy, crustal dynamics, orbit determination for Earth satellites, time synchronization, ionospheric calibration for deep space navigation, atmospheric pressure and temperature modeling using atmospheric occultations and attitude determinations for dynamic platforms. The receiver tracks up to eight satellites simultaneously while measuring the pseudo-ranges and phase delays from L1-C/A, L1-P, and L2-P signals. The hardware and software employ unique signal processing techniques to extract accurate group delays which exhibit sub-centimeter level systematic errors (excluding antenna and multipath) when two or more satellites measurements are differenced. Phase measurements also provide a high degree (sub-millimeter) of accuracy and precision. A dual cross-band dipole antenna mounted to a choke ring backplane reduces multipath interference. It works with a 32 bit RISC processor.

As with the original Rogue, the TTR-4P can extract differential group-delay (P2-P1) and phase (L1-L2) with P-code encryption (A-S) on or off. Full P-code tracking provides highest precision phase and pseudo-range measurements and is the default tracking mode. Whenever the receiver discovers that a GPS satellite has encrypted its P-Code, P-codeless tracking is the automatic fall-back mode. This mode is not entirely codeless, since the receiver continues to track the C/A code normally. The receiver takes advantage of the fact that both L1 and L2 have the same P-code modulation / encryption. Because each carrier has identical modulation, the L1 signal can be cross-correlated with the L2 signal, resulting in both differential phase measurements (L1-L2) and group delay measurements (P1-P2). In P-codeless mode, L1-C/A code and carrier phase data as well as P-codeless data are output at a maximum rate of once per second.

The CCDS Sub-GROUP on GPS and GLONASS Time Transfer Standards (GGTTS) data format version 1 is a standardized format for both data format and data reduction procedure [3]. This format requires a specific output file for each observation channel. Some expectations of even available multichannel operation are:

- The only adjustment made to the GGTTS data format is that instead of putting the observations of each channel in individual files, all results of all channels are output in the same file;
- Thus, when using a common tracking reference date, all receivers world-wide track at the same time all visible satellites in their area. Therefore, any specific tracking schedule is included in the observations;
- Due to the multichannel output at one epoch the data can better match to different tracking schedule partitions for other regions of the Earth (increase of suitable data points);
- An improvement of accuracy for various applications is expected, even for a stand-alone application where noise due to SA-effect is reduced by the square root of the number of simultaneous observations (but there is a certain level where SA-noise cannot be further reduced!).

EXPERIMENTAL SETUP

The setup of the DLR Oberpfaffenhofen TTR-4P station in its branch Weilheim consists of the reference clock CH1-75 (1 pps & 5 MHz), an active H-maser (equal to UTC(DLR)) of the Russian company Kvarz. The antenna position had been determined during a PRARE campaign [4].

The setup looks similar at BIPM site (here Cs-clock Cs(BIPM)). At both sites also an one-channel GPS time receiver has been used, at DLR a TTR6, at BIPM a Sercel NRT1. Both are running with the common BIPM GPS tracking schedule. The overall setup is given in Fig. 1.

Due to some problems with the TTR-4P situated at BIPM another site was involved later: NPL (TTR-4P, TTR5A, Sigma Tau active H-maser - UTC(NPL)). This does not change the general procedure and we will refer to these data below.

SOFTWARE MATTERS

It should be pointed out here again, that we were studying the application point of TTR-4P for time transfer purposes as available presently. Concerning internal receiver details excellent work has been done by our BIPM colleagues [5].

Both DLR and BIPM used different software versions for TTR-4P. BIPM was operating with version 3.0.34.3 whereas DLR's receiver was delivered with the newer version 3.0.34.4 which outputs directly data in GGTTS format. This makes post-processing much more easier compared with the procedure for the older version. Also, the sample rate and other things are more standardized, which is a need even for a worldwide implementation in the timing community.

To the knowledge of the authors to date DLR seems to be the first company running TTR-4P with the new S/W version. This S/W is designed to operate the TTR-4P as a timing receiver [6]. It operates the system as a "stand-alone" unit or in the "Common-View" mode. The program formats data output into the GGTS format and saves it on flash card from "Common-View" operation. It should also output timing information in real time for stand-alone operation.

In stand-alone operation an accuracy is specified by 60 ns and 10 ns with and without SA respectively. By using "Common-View" data, some systematic effects are removed and the accuracy is specified to be typically at 3 ns RMS with or without SA.

A special CLOCK mode is introduced for obtaining timing information from a known location. One can enter the position or determine it applying FIXED mode. In CLOCK mode the S/W tells the receiver to accept the position as completely accurate and change the times to match the pseudo-range from that location. From this also follows that if position is in error, it will not be possible to track satellites.

The default parameters in Tab. 1 are implemented in CLOCK mode (S/W 3.0.34.4), the same parameters were introduced in the receiver running the S/W 3.0.34.3.

Parameter	setting
Site type	CLOCK
Elevation Mask	20.0
Half Life	0.0 min
Nav Hlth	apply
Rf hlth	ignore
Ionosphere Mode	model
RAIM	on protect
Data bit checking	on

Tab. 1: Default parameters in CLOCK mode

The sample rate must be set to 1 sec to be compatible with GGTS tracking mode. Ref-1pps delay can be set, also a antenna cable delay, receiver time delay (from manual), a 1 pps output delay. Some header information can be entered so as class, comm, frame, ims, lab, rcvr, ref. GGTS data format can be logged by using the AUX port.

In CLOCK mode the receiver logs the data in one-second measurements. These data will be collected in 16 minute intervals from the entire 24 hour period. The collection takes place from minute 2 to minute 15 (780 sec), and there is a three-minute break before the next interval begins [6]. It is necessary to set the time to begin the process so that it will match data taken from other receivers. At the end of the 24-hour period, the start time will be automatically increased by 23 hours and 56 minutes. This makes the data collection keep pace with other BIPM data type units.

In the S/W all parameters can be changed too which allows a large flexibility at the application site, but it also offers some drawbacks as different sites may not measure in the same way what degrades or influences the results.

In this study only "standard GGTTs data" were taken at DLR and BIPM site.

"SHIFTED COMMON VIEW"

A problem occurred later by starting to process additional NPL data. This should be explained here. While starting to process the data, a time shift of 18 sec between DLR and the NPL TTR-4P data blocks has been noticed. This 18-sec shift is due to the fact that NPL runs its TTR-4P in 30-sec sample rate. The first versions of TTR-4P software did not accept 1 sec as a sample rate: it had to be multiples of 10 sec. This means result lines are dated HH:MM:SS and HH:MM:30 GPS time and since there is a 12-sec difference between UTC and GPS presently the result lines are dated HH:MM:48 and HH:MM:18 UTC in the data file. Doing such a "Common-View" processing we have to speak about a "Shifted Common View". This is for sure an inconvenience at this point.

The same problem occurred processing BIPM data from the Sercel NRT1 receiver. The track times are 12 seconds apart from DLR (HH.MM:00) standard times because the receiver uses GPS time dates to start and stop tracking. This results also in a "Shifted Common-View" processing.

In preliminary discussion with USNO about long baseline comparisons the same feature could be observed. Their receiver has a sample rate of 10 sec and GGTTs data format is spit out with HH:MM:08 data lines.

We can see here a problem for global clock comparisons in view of standardization which should be simply avoided in future !

OVERALL OBSERVATION PERIOD BETWEEN DLR AND BIPM WITH TTR-4P

First we want to give an overview of all data taken for comparison between DLR and BIPM. In Fig. 2 and Fig. 3 the recorded data block (local clock) - GPS is presented, whereas Fig. 4 gives the "Common-View" result. The result looks strange due to different problems at both sites. The reason will be explained here. Three phases could be identified after some analysis:

- I. from MJD 50699 till 50706.8: problems at DLR site with PRN15,
- II. from MJD 50707 till 50708.4: the only time a normal operation was achieved,
- III. after this period the BIPM receiver failed completely (problems with 4 receiver channels).

ABSOLUTE SYNCHRONIZATION WITH TTR-4P

We analyzed the capability of the TTR-4P to compare the local reference to a dedicated physical clock at a satellite and to GPS time. The result is presented in Fig. 5 till Fig. 7 for PRN22 with respect to DLR site, RMS values 45 ns and 44 ns for clock and GPS time monitoring respectively (linear regression). For GPS time monitoring the noise is mainly due to the SA. In Fig. 8 till Fig. 10 PRN15 is in analysis. It has

to be mentioned here, what has been noted during the processing, that as soon as the TTR-4P at DLR tracks PRN15 all measurements are degraded (cf. Fig. 4). This is supposed to be a S/W bug ! The RMS values are 31 ns (?) and 27 ns for clock and GPS time monitoring respectively (linear regression). After MJD 50707 PRN15 has been deselected in DLR to overcome this problem.

In Fig. 11 till Fig. 13 the BIPM site tracking for PRN15 is shown for comparison, RMS values 155 ns and 6 ns for clock and GPS time monitoring respectively (linear regression).

"MULTIPLE COMMON VIEW" WITH TTR-4P BETWEEN DLR AND BIPM

For this time period the "Common-View" result is shown in Fig. 14. Significant errors occur during periods of PRN15 visibility/reception at DLR site. From MJD 50707 PRN15 has been deselected at DLR's receiver, and the comparison as shown in Fig. 15 worked well: RMS 3.2 ns, rate 6.6 ns/d.

The "Shifted Common View" feature was not obtained in this case, because BIPM has modified its software to track in 1-sec sample rate.

CONVENTIONAL "COMMON VIEW" BETWEEN DLR AND BIPM

A "Shifted Common View" with one-channel receivers has been made between DLR and BIPM (TTR5, NRT1). The result for MJD 50692 till 50721 is given in Fig 16, RMS 4.4 ns, rate 8.4 ns/d. Partly problems occurred at DLR site (receiver lost/loses time?), and DLR only uses a partition of the international tracking schedule. Thus, the small number of data can be explained.

A discrepancy of about 30 ns can be obtained between multichannel and one-channel operation coming from calibration problems.

DATA FROM NPL

Due to the failure of BIPM receiver, we decided to ask our colleagues at NPL to support the analysis with NPL data (thanks John Davis). Thus, data have been sent to us and processed in a very similar way. GPS time monitoring at NPL site using PRN15 is given in Fig. 17, RMS 5 ns. It should be noted that the monitoring of PRN15 clock gave a RMS of 118 ns (BIPM 155 ns), and shows that the value of 31 ns at DLR was caused by a receiver error.

A "Shifted Common View" between DLR's and NPL's TTR-4P receivers is presented in Fig. 18 with a RMS of 4.1 ns, rate 9.4 ns/d. A systematic effect is clearly visible; maybe this comes from the "Shifted Common-View" mode or other uncertainties not compensated. Also, a conventional "Common View" has been made. This is shown in Fig. 19, RMS 7.4 ns, rate 9.7 ns/d. The rare data number is caused by the same problems as explained above. NPL told that the TTR-4P data are offset by "around" 39 μ s. Considering this approximate input, a calibration discrepancy of about 140 ns still remains, but the rates do agree well.

CONCLUSION: PROBLEMS AND RECOMMENDATIONS

Some problems are summarized here:

- The new S/W (3.0.34.4) has a bug in view of PRN15 reception which causes bad data for all other measurements during reception of this satellite;
- With the new S/W version (3.0.34.4) the receiver seemed to be not stable in long term. At DLR a need to touch the receiver's console from time to time has been discovered, otherwise the receiver hung up ("Tamagoshi"-like behavior);
- In the S/W 3.0.34.4, the RINEX observable data could not be downloaded neither in DLR or in BIPM where this version has been briefly tested. Thus, no frequency comparison using carrier phase can be done;
- In the new S/W (3.0.34.4) no mode guarantees a strict operation according to the Technical Directives [3]. For instance, the present CLOCK mode parameters can be modified by the user (i.e. sample rate, ionospheric model, etc.), with the consequence that similar operation at different sites are not assured;
- No ready manual is available; up to now the old document from S/W 3.0.34.3 has to be used, plus a very drafty version from the new S/W [6];
- The start-up procedure is not optimized. In (default) CLOCK mode the receiver did not track although accurate position data have been used. Thus, first the sample rate had to be increased to 10 sec, and the navigation parameters "position and clock" changed to be "close". After the receiver starts to track satellites and has been synchronized the sample rate must be set to 1 sec and "position and clock" to "good";
- In the new S/W (3.0.34.4) the start time is not attached to a particular date, so it is difficult to check if the start time introduced is the correct one;
- In the new S/W (3.0.34.4) some entries can only be made by means of a terminal (i.e. start time);
- In the S/W (3.0.34.3) the ionospheric model and measurements are not available simultaneously (only one or the other);
- According to the used sample rate, only "Shifted Common Views" may be possible.

This results in the following recommendations on the TTR-4P receiver:

- The S/W (3.0.34.4) is going in the right direction especially by making model and measured ionospheric measurements available at the same time. But its use cannot be recommended until the PRN 15 bug is corrected, the RINEX observable are downloadable, and a cold-start CLOCK procedure is possible;
- It would also be of interest to be able to input all settable parameters from the front panel, and to have an operational mode following strictly the recommendations expressed in the Technical Directives [3];

and the method:

- Use of a reference date to keep multichannel "Common-View" observations coherent with classical

"Common-View" schedules;

- Ensure 1-sec sample rate at all labs and "HH.MM:00 data lines" or any other recommended in the Technical Directives [3], and do not "shift" the "Common Views".

Multichannel "Common View" is a very promising technique, and more investigation work is needed, using reliable hardware and bug-free software for "Multiple Common View". The use of high rate data in form of carrier phase observable should bring an improvement in the accuracy of measurements.

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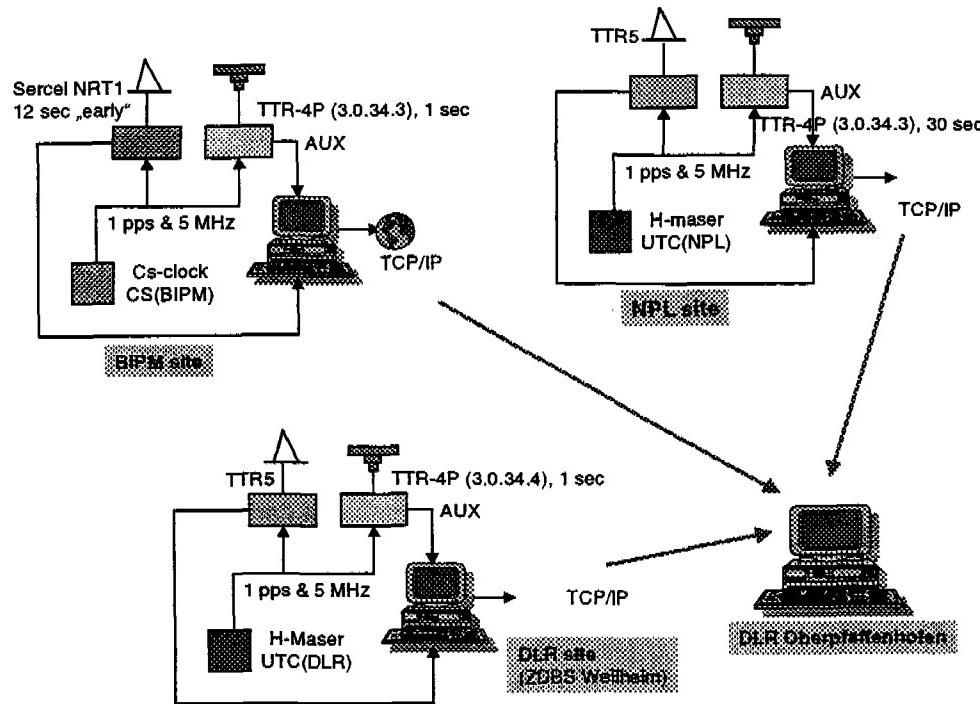


Fig. 1: Overall experimental setup

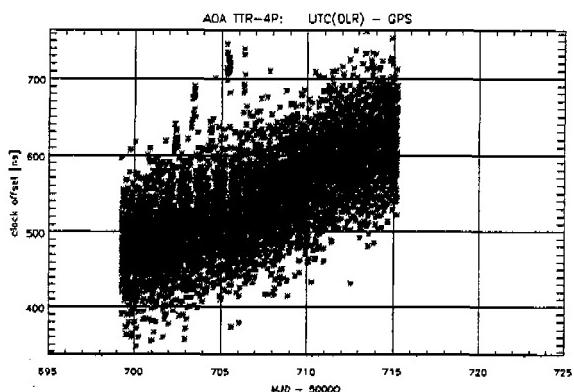


Fig. 2: GPS time reception at DLR site over all satellites with TTR-4P, RMS 47 ns

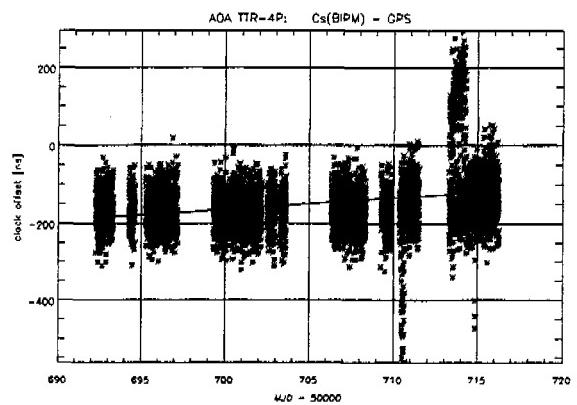


Fig. 3: GPS time reception at BIPM site over all satellites with TTR-4P

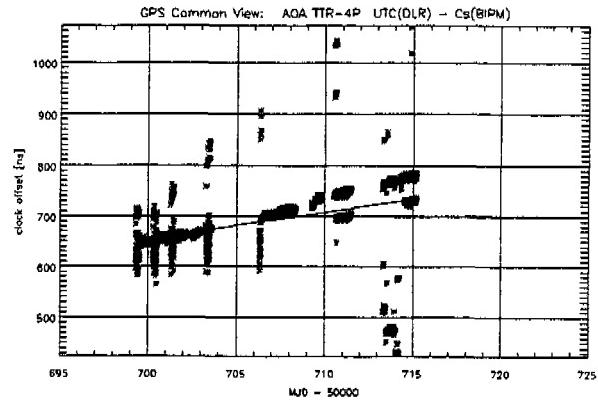


Fig. 4: GPS "Shifted Common View" between DLR and BIPM with TTR-4P over whole experimental period

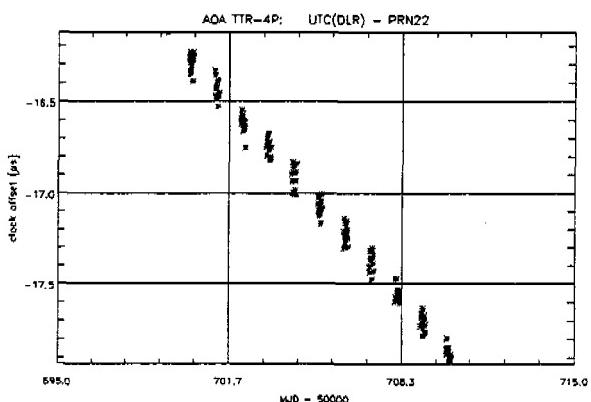


Fig. 5: PRN22 clock monitoring at DLR site with TTR-4P

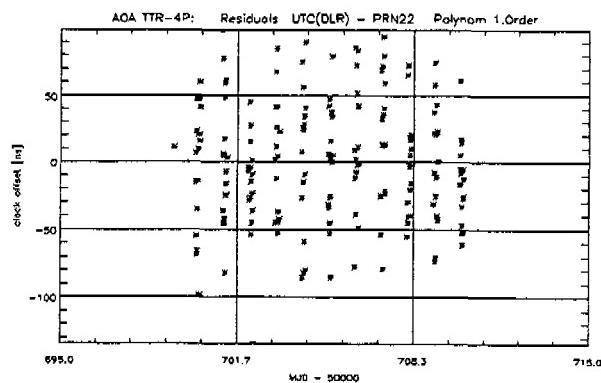


Fig. 6: Residuals of PRN22 clock monitoring at DLR site, RMS 45 ns

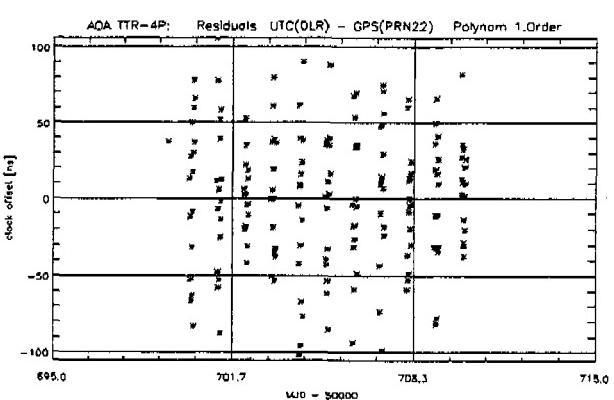


Fig. 7: Residuals of GPS time monitoring at DLR site using PRN22, RMS 44 ns

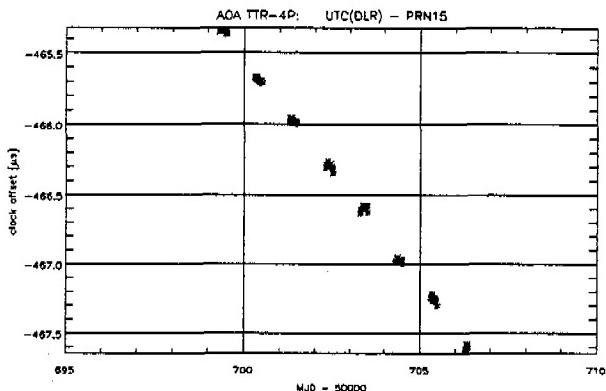


Fig. 8: PRN15 clock monitoring at DLR site with TTR-4P

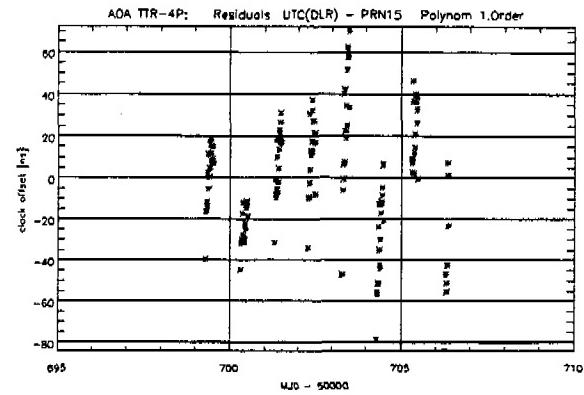


Fig. 9: Residuals of PRN15 clock monitoring at DLR site, RMS 31 ns

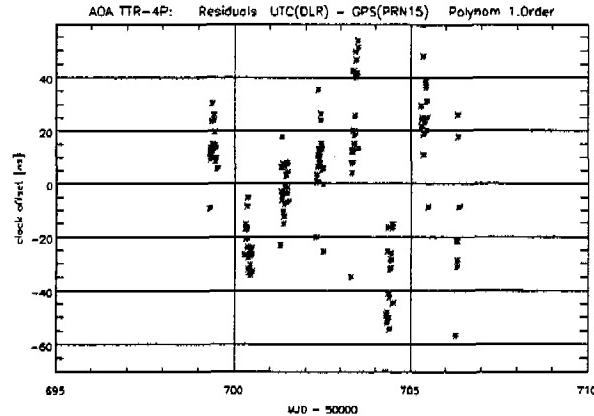


Fig. 10: Residuals of GPS time monitoring at DLR site using PRN15, RMS 27 ns

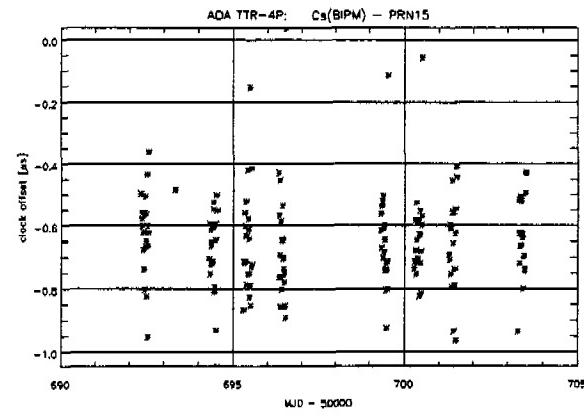


Fig. 11: PRN15 clock monitoring at BIPM site with TTR-4, RMS 155 ns

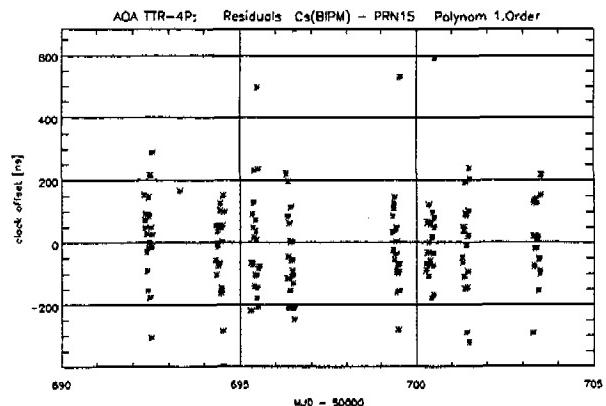


Fig. 12: Residuals of PRN15 clock monitoring at BIPM site, RMS 155 ns

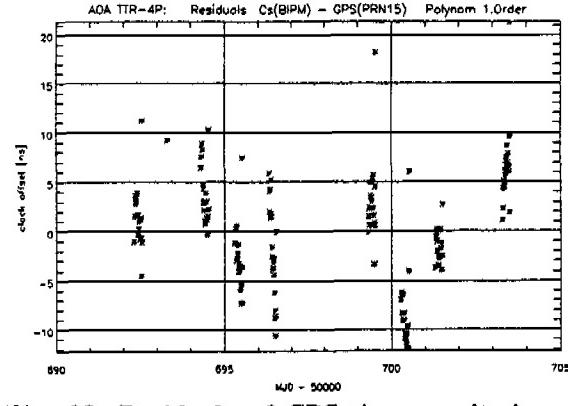


Fig. 13: Residuals of GPS time monitoring at BIPM site using PRN15, RMS 6 ns

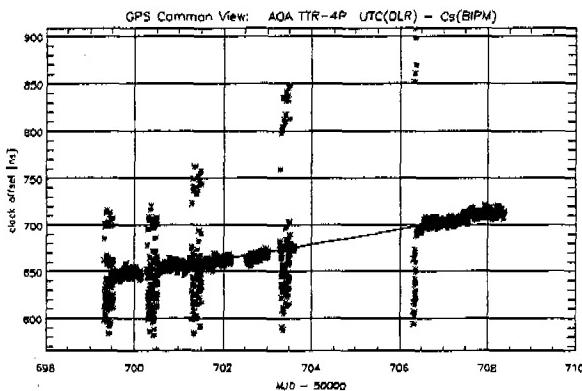


Fig. 14: GPS "Common View" between DLR and BIPM with TTR-4P over period with PRN15 problems at DLR site

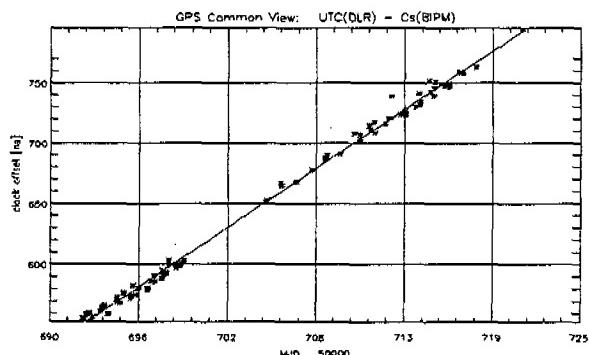


Fig. 16: Conventional GPS "Common View" (but also "Shifted" by 12 sec) between DLR and BIPM with one-channel receivers, RMS 4.4 ns

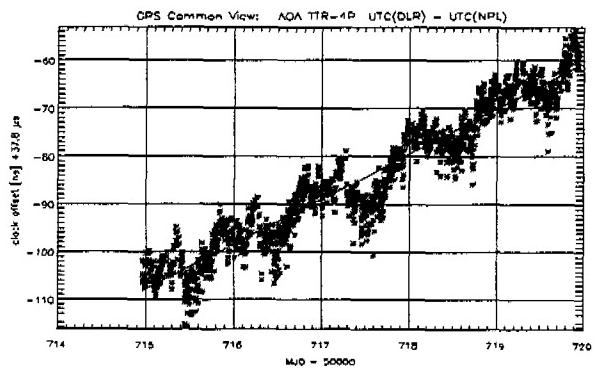


Fig. 18: GPS "Shifted Common View" between DLR and NPL with TTR-4P over period with good data at both sites, RMS 4.1 ns

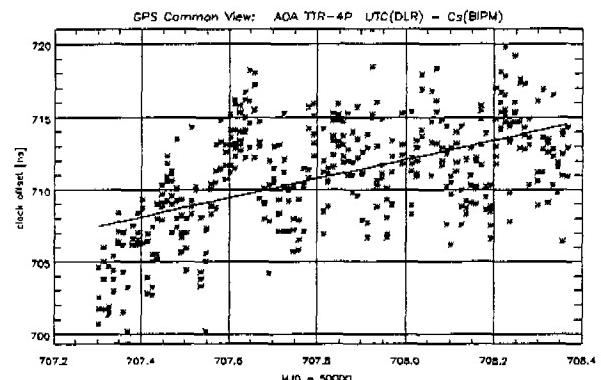


Fig. 15: GPS "Shifted Common View" between DLR and BIPM with TTR-4P over period with good data at both sites, RMS 3.2 ns

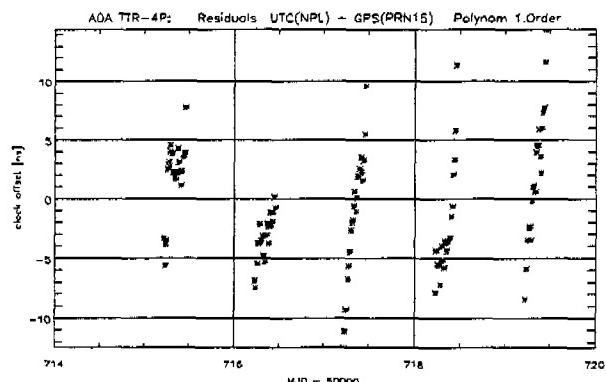


Fig. 17: Residuals of PRN15 clock monitoring at NPL site, RMS 5 ns

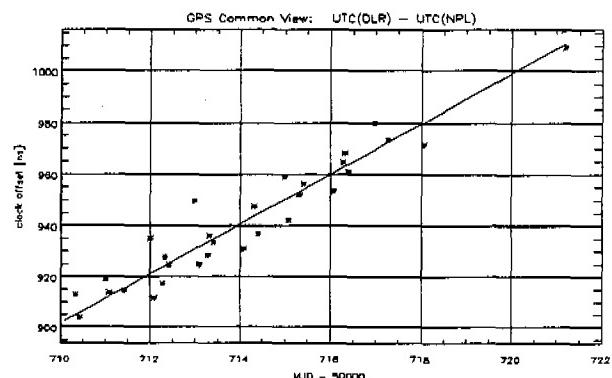


Fig. 19: Conventional CV between DLR and NPL, RMS 7.4 ns

Questions and Answers

ROB DOUGLAS (NATIONAL RESEARCH COUNCIL OF CANADA): There have to be questions after three papers like these, so I will try my hand at getting the flow going. One of the exciting things about a multi-channel receiver used in this mode is the very careful effort that manufacturers have put into having different channels calibrated, one with respect to the other. I am wondering if any of the three paper presenters has a comment on the use of these channels for timing calibration of the entire system by injecting a satellite simulator signal.

JOERG HAHN (DLR, INSTITUT für HOCHFREQUENZTECHNIK): My comment: What I have not shown here in this presentation, is the comparison of our results with a one-channel common-view operation, which is shown in the paper. We had some discrepancies in the order up to 120 nanoseconds compared to the conventional common views. But, of course, we need to consider what each channel has in calibration delays, and we are changing. In the meeting on Monday, we had the good proposal which could be done to track one satellite on several channels of the receiver. This could be a very good method of differential calibration between the receiver channels. But this is a matter for the software. Maybe Allen Osborne Associates could do something about this.

ROB DOUGLAS: Do the other two authors have a comment on calibrations?

MIHRAN MIRANIAN (USNO): I was going to say the same thing, that the simple way to do it would be to just track one satellite on all channels. Then you could immediately determine the inter-channel biases, if there are any, and correct for them.

ROB DOUGLAS: My perspective on this that I am going to inflict on you is that the calibration that I think is important is a calibration of all the filters and everything in the system. So absolute calibration, I think can be handled much better by multi-channel than by single-channel receivers. We are a long way from doing that, but maybe not as long a way as we think.

JUDAH LEVINE (NIST): I think, in many cases, a multi-channel receiver does not really have completely separate channels. So very often the many channels are implemented in the digital processing, whereas the analog system, the RF system is common. The result is that there are not eight filters to deal with, there is only one filter; the rest of it is just digital signal processing, and it is not quite as hard as you think.

The second thing is that there is a real difference between a receiver like the TTR-4P and a receiver like the Motorola Oncore because in the TTR-4P the same satellite will often come up in a different channel in a subsequent second. The result is that it is not true that if you are tracking Satellite Number 12, initially in the first channel it stays in the first channel for its entire time that you see it; sometimes it appears in another channel. You can keep track of that, but if you do not, you have lost it. Whereas, in a receiver like the Motorola Oncore, so far as we know, the satellite always stays in the same channel. Therefore, trying to do calibration, in a TTR-4P, is a very much more complicated business because of the fact that the satellites jump around among the channels.

JOERG HAHN: I have also solved this problem, it runs a display and quite rapidly.

JUDAH LEVINE: I do not think it is a problem. I think it is viewed as a feature.

JOERG HAHN: Maybe.